PION PRODUCTION

MEASUREMENT OF THE TOTAL CROSS SECTION FOR THE REACTION $p+p \rightarrow p+p+\pi^0$

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The IUCF Cooler is the first of many newly constructed ion storage rings to make use of electron cooling. The cooling process leads to a decrease in the phase volume of the ion beam; this leads to beams with small emittance and unprecedented energy resolution. The first nuclear physics experiment to use electron cooling, CE01, involves the study of the $p+p \rightarrow p+p+\pi^0$ reaction near threshold. A thin internal H_2 gas jet serves as the target and a detector array is used to measure the energy and momentum of the coincident protons in the exit channel. The Cooler, together with a thin internal target, is well suited for threshold measurements. It provides a well defined interaction energy which is crucial since, near threshold, the cross section varies rapidly with energy. The Cooler also serves as a synchrotron providing the necessary proton energies from 280 - 320 MeV which were previously not available at IUCF. The purity of the internal gas jet (absence of target windows) greatly reduces the background from N-nucleus pion production which has a much lower threshold energy. Previous experiments[1,2] were limited to T_p>320 MeV because of this background.

The operation of the Cooler is cyclic. First, protons of 45 MeV are accumulated in the ring using stripping injection of 90 MeV H_2^+ from the cyclotron. The 45 MeV beam is then allowed to cool and injection is repeated. The process of injection followed by cooling can be repeated with very little loss of the already cooled beam.[3] The beam is then ramped to the desired energy where typical beam currents of 10-20 μA were achieved. After additional cooling at the final energy, the target was turned on and data acquisition started. After most of the beam was lost due to beam-target interactions, the target and data acquisition were turned off, the Cooler was reset and the entire cycle was repeated. The timing sequence for a typical CE01 production run is shown in Fig. 1. Duty factors of 50-60% were typical during production runs.

The target used in CE01 is an internal H_2 gas jet emerging from a nozzle cooled to 40°K. The gas inlet line is equipped with fast switching valves which allows the target gas to flow only during data acquisition. The jet is mounted in a 1.3 m long, general-purpose target chamber. There are three locations in the chamber available to the jet, two of which (the central and downstream) were used in separate production runs. Three stages of differential pumping decouple the jet from the nominal 10^{-9} Torr vacuum of the ring. Target thicknesses of several times 10^{15} atoms/cm^2 were achieved. With a cooled nozzle, about 70% of the target thickness is contained in the jet while the rest is due to the uniform gas density in the central region of the differential pumping system. A thin stainless steel

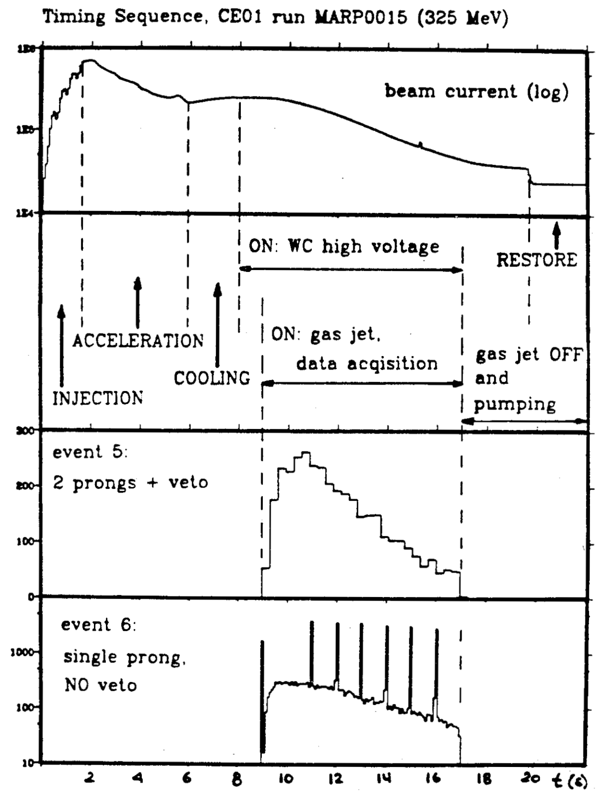


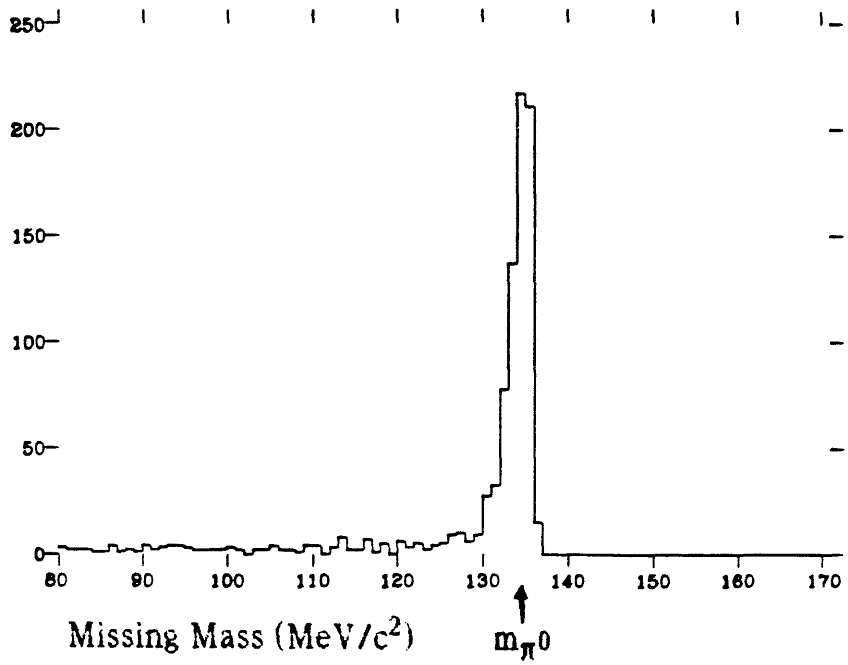
Figure 1. Timing sequence for a CE01 production run.

window at the downstream end of the chamber allows the reaction products to exit.

Close to threshold, the two protons in the exit channel of $p+p \rightarrow p+p+\pi^0$ are confined in the lab to a narrow cone in the forward direction. A detector array has been designed and constructed to detect coincident protons in this cone with good energy and angular resolution. The detector consists of three planes of scintillators, a front detector (F), a stopping detector (E), and a veto detector (V). The planes are segmented in order to obtain fast information on the charged-particle multiplicity of an event. The detector array also consists of two X-Y wire chambers. One chamber is rotated by 45°; this removes the ambiguity associated with multi-prong events. The wire chambers serve to determine the direction of the outgoing protons. The cylindrically symmetric detector array covers polar angles from 2°-11° with the target in the central position and from 4°-20° with the target in the downstream position.

Once the 4-momenta of the two protons are known, the parameters of the unobserved particle can be deduced. Fig. 2 shows the reconstructed missing mass and clearly indicates that very little background is present. In order to obtain an absolute cross section for $p+p \rightarrow p+p+\pi^0$, the target thickness and beam current must be known. These quantities are difficult to determine individually but their product, the luminosity, can be measured using pp elastic scattering for which the cross section is known. Elastically scattered protons were detected at the same time and by the same detector as the pion production events. In addition, elastic recoil protons were observed by two position-sensitive silicon detectors, located in a horizontal plane on either side of the jet. Their position-sensitive surface is parallel to the beam and separated from it by 11 cm. The recoil detectors serve

Figure 2. Missing mass spectrum, p+p→p+p+(X), for a bombarding energy of 282.5 MeV.



two purposes: they eliminate contribution from beam energy background protons, and because of their position sensitive surface, provide a relative measure of the luminosity along the beam. The latter must be known in order to correct for the contribution to pion production from the gas outside the acceptance of the silicon detectors.

With two production runs in the first quarter of 1990, CE01 has concluded taking data. Currently the analysis of the data is in progress. A Monte Carlo simulation is used to model various aspects of the detector response, such as geometrical losses through the central hole of the detector array, loss of events with both tracks in the same E segment, effects of an extended target, reaction losses in the scintillators, multiple scattering and energy losses, and wire chamber inefficiencies for both pp elastic and $pp\pi^0$ reactions.

An absolute value of the bombarding energy with an error of ±200 keV is deduced from the maximum polar angle of the two protons which is strongly dependent on the incident energy. The Monte Carlo code is used to fit the angular distribution of the protons and provides an absolute energy calibration. Fig. 3 shows the angular distribution of protons and the Monte Carlo fit to the distribution.

A summary of the production running parameters and statistics is shown in Table I. The analysis of CE01 is continuing and data in publishable form are expected by the end of the third quarter of 1990.

1. A.F. Dunaitsev and Yu.D. Prokoshkin, JETP. 36 6 (1179).
2. T.D.S. Stanislaus, *"A Study of the Reaction $p+p \to p+p+\pi^0$ From 320 to 500 MeV"*, Ph.D. Thesis, University of British Columbia, 1987.
3. R.E. Pollock, IUCF Scientific and Technical Report, ed. E.J. Stephenson, May 1988–April 1989, p. 108.

Figure 3. Polar angular distribution for the final state protons in $p+p \rightarrow p+p+\pi^0$. The points are experimental data, the histogram is a result from a Monte Carlo simulation. The bombarding energy is adjusted in the simulation to give the best fit to the data (T_p=282.5±0.2 MeV).

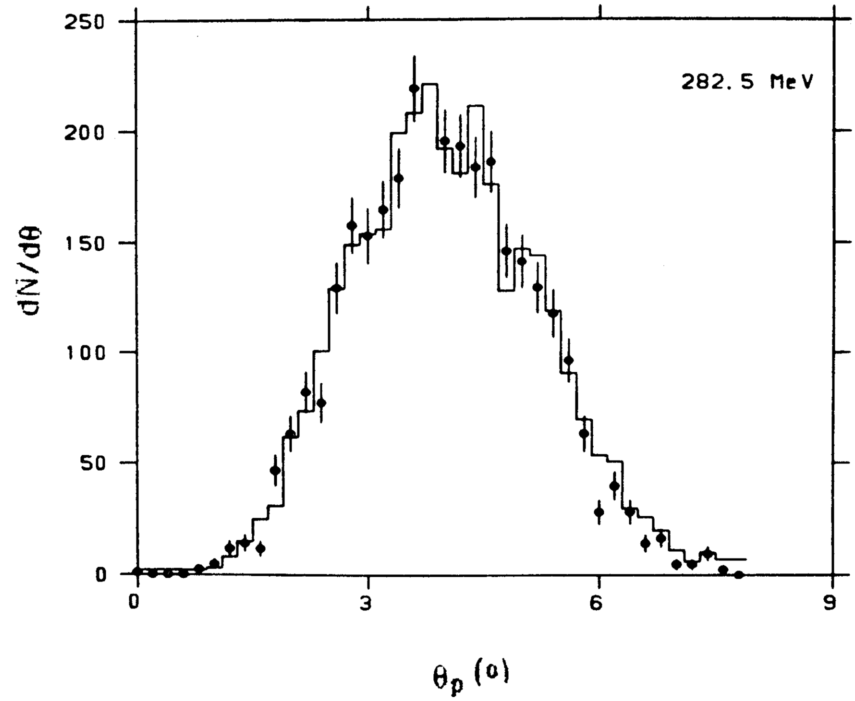


Table I.

CE01 Production Summary

<u>Machine Performance</u>	
Beam Energies:	283-325 MeV (9 values)
Beam Current:	5-25 μA
Target Thickness (cooled jet):	$2\times10^{15}-5\times10^{15}$ atoms/cm^2
Luminosity	
(Acq. Start):	$2\times10^{29}-5\times10^{29}\text{cm}^{-2}\text{s}^{-1}$
(Time Avg.):	$3\times10^{28}-1\times10^{29}\text{cm}^{-2}\text{s}^{-1}$
Beam Lifetime with Target:	4-6 s
<u>Run Statistics</u>	
Time: Production: 110h	Setup: ~200h
Integrated Luminosity (Production):	16 nb^{-1}
<u>Data</u>	
Total # of ppπ^0 events:	24000
Statistical Error:	1-3% per energy point
Systematic Error:	10% (est.)